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Vertical cavity surface-emitting lasers (VCSELs) are becoming increasingly important for short-haul optical fiber transmission systems. Given the commercial success of GaAs-based 850nm VCSELs, dramatic enhancements in transmission bandwidth and distance can be achieved in conventional single- and multi-mode fiber by extending the emission wavelength to the 1300nm-1550nm range. GaInNAs is a promising active layer material grown on GaAs that can achieve 1300nm emission [1], and electrically pulsed broad-area GaInNAs VCSELs [2,3] have been realized. Here we take advantage of the properties of GaAs-based materials—thermally-conductive high contrast mirrors and AlAs-oxide current apertures—to demonstrate for the first time low-threshold (~1 mA) GaInNAs VCSELs emitting at a wavelength of 1200 nm under continuous-wave room temperature operation.

The device structure is shown schematically in figure 1. The bottom mirror consists of a 22.5-period n-doped GaAs/AlAs distributed Bragg reflector (DBR) designed for a center wavelength λ near 1200nm, the top mirror is a 22-period p-doped DBR whose reflectance is enhanced by a Ti/Au contact electrode, and the GaAs λ cavity contains three 70Å $Ga_{0.3}In_{0.7}N_{0.02}As_{0.98}$ quantum wells (QWs) separated by 200Å GaAs barriers. The epilayers were grown by molecular beam epitaxy using solid-source arsenic and a rf nitrogen plasma source. After growth, the first 17 mirror periods of the top mirror were dry etched and subsequently capped with SiO_2, and the remaining three periods were etched to expose the AlAs for lateral oxidation, which formed square unoxidized apertures as small as 3.6 μm on a side. After the top contact metalization, devices were mounted without heat sinking on a glass slide for optical emission through the substrate, which was contacted electrically with indium solder.

The output power and voltage vs. injection current for a 5μm x 5μm device operating CW at room temperature is shown in figure 2. The threshold current is approximately 1.3 mA, and the slope efficiency is 0.045 W/A. CW operation was possible in spite of an extremely high threshold voltage of 10.3 V which resulted from unoptimized doping and composition profiles at the heterointerfaces of the p-DBR. This created a large degree of self heating which limited the maximum output power to 0.080 mW at 3.8 mA. Figure 3 shows emission spectra at threshold, with a lasing wavelength of 1201.54 nm, and at 2.6 times threshold. The device lased in a single transverse and longitudinal mode, and far above threshold, the side mode suppression ratio was in excess of 40 dB. As seen in figure 4, the wavelength shifted with dissipated power at a rate of 0.0924 nm/mW. Given a wavelength shift with temperature of 0.0743 nm/K obtained from broad area VCSELs [4], this indicates a calculated temperature rise of ~60K above the ambient at peak output power and a thermal impedance of 1.24 K/mW. CW laser operation also occurred for device sizes ranging from 3.6 μm to 6.4 μm, with threshold currents from 0.94 to 2.3 mA and slope efficiency as high as 0.049 W/A.

In summary, we have demonstrated low-threshold GaInNAs VCSELs operating continuous-wave at room temperature, with an emission wavelength of 1200 nm. Higher output power will be possible by reducing the resistance of the p-DBR, and 1300 nm emission should be achieved by increasing the indium and/or nitrogen content of the GaInNAs/GaAs multiple quantum well active layer. This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48

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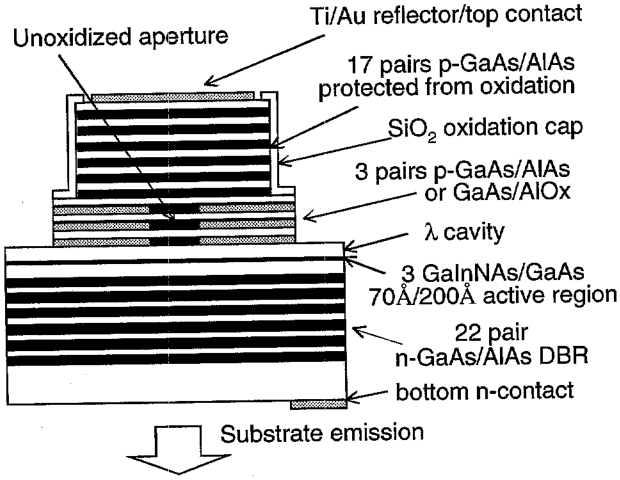

Fig. 1. Schematic diagram of GaInNAs vertical cavity laser.

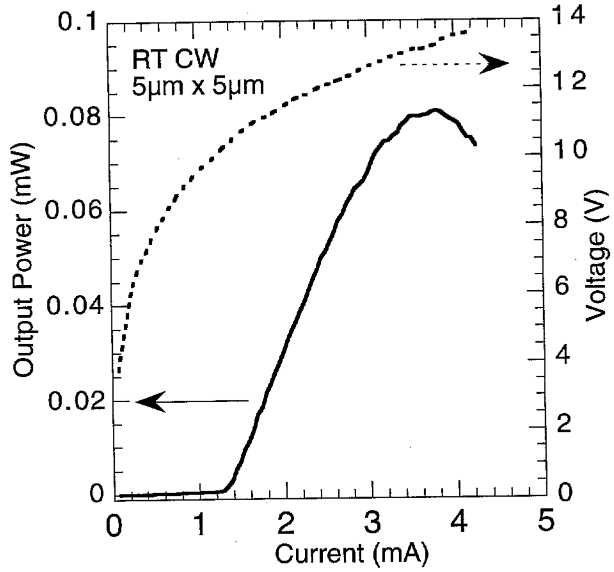

Fig. 2. Light output power and voltage vs. injection current.

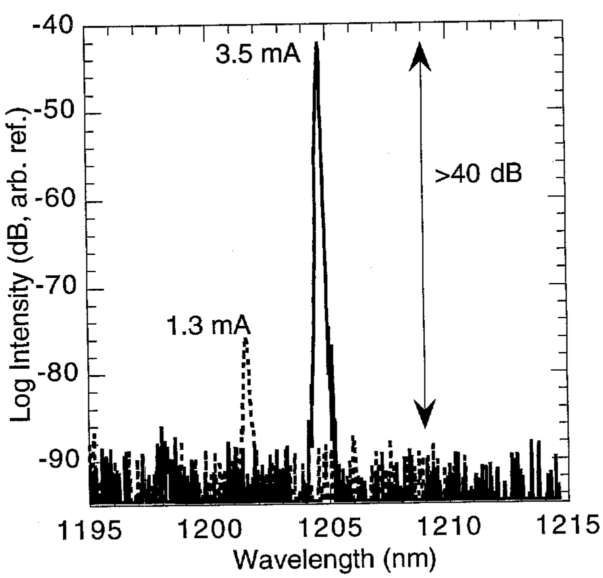

Fig. 3. Emission spectra at 1.3 mA (~I_{th}) and 3.5 mA (~2.6 I_{th}).

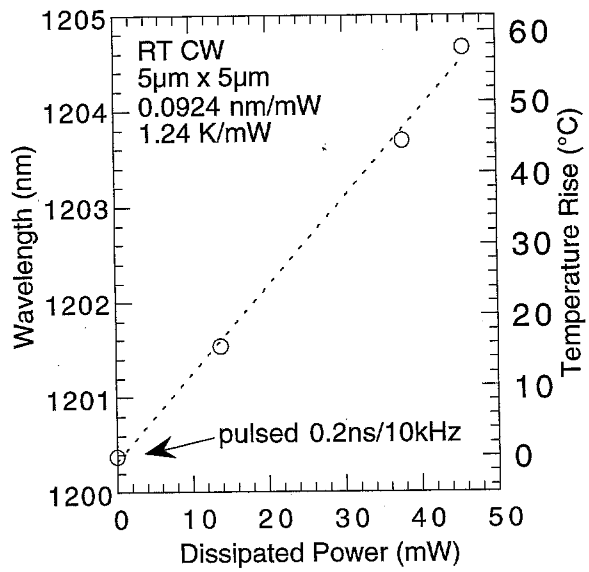

Fig. 4. Wavelength shift and corresponding calculated temperature rise vs. average dissipated power. The data point near the origin is obtained by pulsed measurement; the others are CW.